Pentium® II Processor – Low Power Thermal Design Guide

Application Note

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1.0 Introduction

This document provides thermal performance information for the Pentium® II processor – Low Power with an integrated 256-Kbyte L2 cache. The Pentium II processor – Low Power is available at 266 MHz and 333 MHz, with a system bus speed of 66 MHz. The Pentium II processor is packaged in a PBGA-B615 package (also known as BGA1), with the backside of the silicon die exposed. The thermal solution focus is on heatsinks and fans to meet the performance requirements of the Pentium II processor – Low Power.

This application note:

- Introduces the specifications for the Pentium II Processor – Low Power
- Defines target thermal parameters and clarifies terminology
- Identifies the concepts and airflow calculations used to design thermal solutions. Sample calculations are also provided.
- Identifies the z-height constraints of a thermal solution for a single-slot CompactPCI (CPCI) design
- Discusses interface material and attachment methods for thermal solutions
- Provides a list of thermal solution vendors

2.0 Importance of Thermal Management

The objective of thermal management is to ensure that the temperature of each component is maintained within specified functional limits. The functional temperature limit is the range within which the electrical circuits can be expected to meet their specified performance requirements. Operation outside the functional limit can degrade system performance and cause reliability problems.

The case temperature is the surface temperature of the package at its hottest point, typically at the geographical center of the chip. Over time, temperatures exceeding the case temperature limit can cause physical destruction or may result in irreversible changes in operating characteristics.

3.0 Pentium II Processor — Low Power Thermal Specifications

The power dissipation and case temperature specifications for the 266 MHz and 333 MHz Pentium II Processor — Low Power are shown in Table 1.

To ensure functionality and reliability of the Pentium II processor – Low Power, the maximum device junction temperature must remain below 100° C. Since the backside of the silicon die is exposed, the case temperature is the same as the junction temperature.

The thermal characterization data described in Table 2 illustrates that a thermal solution may be needed depending on the system's operating ambient temperature and the system airflow that can be provided. The size of the heatsink and the amount of airflow are interrelated and can be optimized for a given system. For example, an increase in heatsink size decreases the amount of airflow required. In a typical system, heatsink size is limited by board layout, spacing, and component placement. Airflow is limited by the size and number of system fans and their placement in relation to the components and the airflow channels. Acoustic noise and life-expectancy constraints may also limit the size or types of fans used in the system.

Table 1. Pentium® II Processor — Low Power Power Dissipation and Case Temperature

Frequency	Package Type	Total Pins	Package Size	Ball Array	Typical Power (W)	Maximum Power (W)	Max Case Temp (°C)
266	PBGA	615	31 mm x 35 mm	24 x 26	7.0	9.8	100
333	PBGA	615	31 mm x 35 mm	24 x 26	8.8	11.8	100

Table 2. Pentium® II Processor — Low Power Thermal Characterization Data

Heatsink	Dimensions [mm]	θ_{ca} or θ_{ja} (°C/W) vs. Airflow (LFM)				
		0	100	200	400	600
Sumitomo Corrugated HS	50 X 45 X 10		6.0	4.0	2.9	2.2
Thermalloy Extruded HS	45 X 55 X 11		7.4	5.1	3.5	2.8
AAVID (pin fin HS)	49 X 49 X 9		7.5	5.2	3.6	2.9
AAVID (uni. dir. HS)	47 X 47 X 6.5		7.3	5.0	3.6	3.0
Panasonic fan	44 X 44 X 7	3.21				
Sunonwealth fan	50 X 50 X 9	3.16				
Shicoh fan	44 X 44 X 6.5	3.24				

3.1 Interface Material

The optimal material for interfacing the silicon die surface to the heatsink must be determined for each application. Available interface materials include:

- Thermagon T-Pli 210 Elastomer
  - — Thickness: Approximately 5-10 mils (0.127 - 0.254 mm)
  - — Thermal resistance: Approximately 0.69 °C/W
  - — Max. Pressure applied to material: 40 psi. (276 kPa)
  - — When this material is used, the thickness should be validated to achieve the targeted thermal resistance required.
- Thermagon PCM910 Phase Change Material
  - — Thickness: Approximately 5-10 mils (0.127 - 0.254 mm)
  - — Thermal resistance: Approximately 0.57 °C/W
  - — Max. Pressure applied to material: 40 psi. (276 kPa)
  - — When this material is used, the thickness should be validated to achieve the targeted thermal resistance required.

It is important to maintain proper thermal compression, but do not exceed 60 psi (413 kPa) on the processor die surface. Compressive force on the die may pump out the grease or phase change the material. Refer to Table 4, "Vendor List" on page 14 for vendor information.

3.2 Attach Methods

The heatsink attachment mechanism secures the heatsink to the board, provides adequate pressure to the heatsink for optimum thermal performance, and protects the backside of the die surface. The attachment mechanism should not interfere with the thermal ability of the package or inhibit the performance of the processor in the application.

Several types of attachment mechanisms are available. The first consists of pins that pass through the heatsink and printed-circuit board (PCB) mounting holes. This can be done with a flange on the heatsink or by holes within the heatsink itself. A second type consists of a clip that wraps around, or attaches to, the heatsink and attaches to the PCB through specified mounting holes. A third consists of screws passing from the top or bottom of the board into the heatsink assembly.

Note: For surface mount height considerations, keep in mind that the PBGA package is reflowed to the board. The ball height collapses approximately 20%-30%, or 0.11 mm to 0.16 mm. To compensate for surface mount height variation, springs may be used in conjunction with the pins to maintain a compressive force (5-10 lbf) on the thermal interface material.

For pins and clips, the insertion and extraction forces are recommended to be less than 15 lbf. The attachment mechanism should be supplied by the heatsink vendor.

4.0 Thermal Parameters

4.1 Ambient Temperature

Ambient temperature (T_A) is the temperature of the undistributed air surrounding the component. Ambient temperature is usually measured at a specified distance from the component. In a system environment, ambient temperature is the temperature of the air upstream to the component and in its close vicinity. In a typical laboratory test environment, ambient temperature is measured 12 inches (or as close to 12 inches as possible) upstream from the component to represent the ambient temperature with air flowing past the system. When natural convection is used in a system, the ambient temperature is measured directly underneath the board near the component. In an active cooling system, the ambient temperature is the inlet air to the active cooling device.

4.2 Measuring Case Temperature

To verify that the proper case temperature (T_C) is maintained for the Pentium II Processor — Low Power, attach the thermocouple to the die surface, centered above the processor package. To minimize measurement errors, the following techniques and materials are recommended:

- Use 36 AWG or finer diameter K, T, or J type thermocouples. Intel's laboratory testing was performed using a thermocouple offered by Omega Engineering, Inc. (part number: 5TC-TTK-36-36).
- Attach the thermocouple bead or junction to the center and top surface of the package using a cement or glue that is highly thermally conductive. Intel's laboratory testing was performed using Omega Bond* (Part number: OB-101).
- Attach the thermocouple at a 0° angle on the center of the top surface of the package.

4.3 Calculating Case-to-Ambient Thermal Resistance

The case-to-ambient thermal resistance determines the performance of the thermal solution and can be calculated using the following equation:

Equation 1. $\theta_{CA} = (T_C - T_A)/P$

where:

θ_{CA} = case-to-ambient thermal resistance (°C/W)
T_A = ambient temperature (°C)
T_C = case temperature (°C)
P = device power dissipation (Watts)

The lower the thermal resistance between the case and the ambient air, the more efficient the thermal solution will be.

The thermal resistance values depend on the heatsink material, thermal conductivity, thermal interface material, and geometry of the thermal cooling solution and airflow rates.

4.3.1 Example Airflow Calculations

Assuming *worst-case* conditions at 333 MHz:

- The case temperature at the processor die surface is 100° C
- The ambient temperature is 50° C
- The TDP max dissipated by the Pentium II Processor — Low Power is 11.8 W
- The case-to-ambient thermal resistance (θ_{CA}, calculated using Equation 1 above) is 4.24° C/W.

Knowing the θ_{CA} value allows the system designer to estimate the airflow required to keep the case temperature at 100° C. As indicated in Figure 1, the fan solutions would require no additional system airflow, since the thermal resistance is less than 4.24° C/W. The corrugated heatsink would require 200 LFM and the extruded heatsinks would require approximately 325 LFM.

Assuming *typical* conditions at 333 MHz:

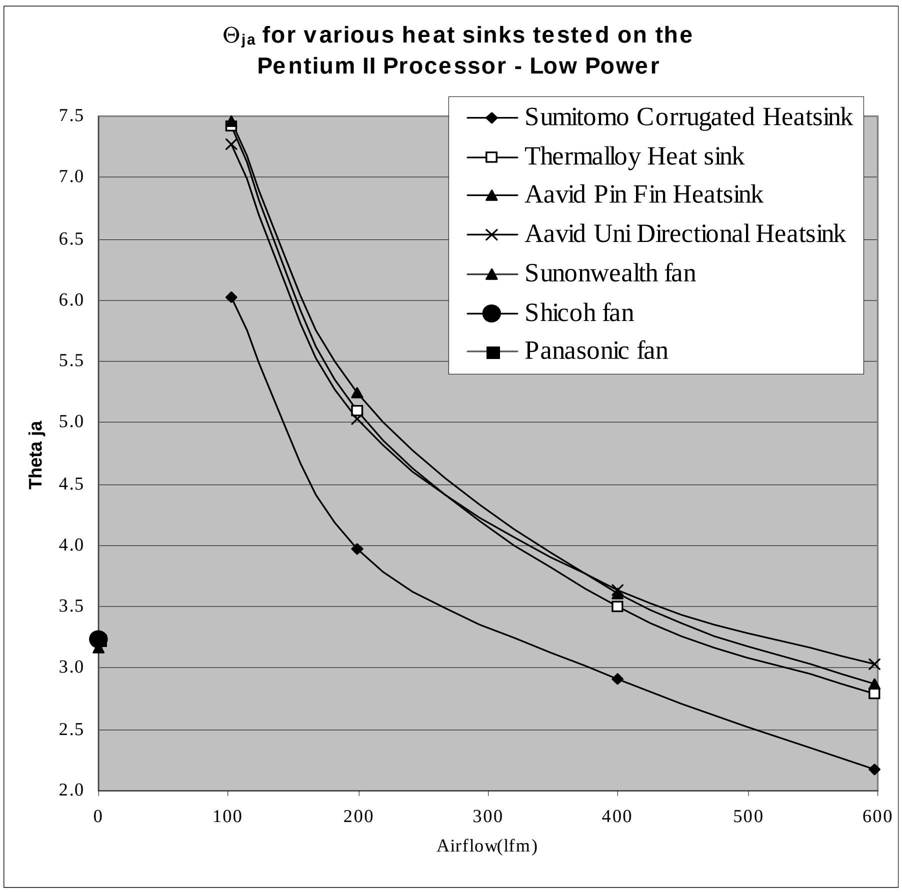
- The case temperature at the processor die surface is 100° C
- The ambient temperature is 50° C
- The TDP typical dissipated by the Pentium II Processor — Low Power is 8.8 W
- The case-to-ambient thermal resistance (θ_{CA}, calculated using Equation 1 above) is 5.68° C/W.

As indicated in Figure 1, the fan solutions would require no additional system airflow. The corrugated heatsink would require ~125 LFM, and the extruded heatsinks would require approximately 175 LFM.

4.4 Airflow Measurement

The airflow, or air velocity flowing across the components, can be measured using a portable air velocity meter (anemometer). The meter contains two temperature sensing elements. One element is used to track the air stream temperature and the second element is heated by an electrical current to maintain a constant temperature above the air stream temperature. As the air stream takes heat energy away from the heated element, more current is required to maintain the temperature differential. The required electrical current is proportional to the air mass velocity displayed on the meter. This meter is available from Kurz Instruments. Refer to the vendor list in Section 7.0 for vendor information.

Figure 1. Pentium II Processor — Low Power Thermal Resistance vs. Airflow



5.0 Thermal Solution Options for the Pentium II Processor — Low Power

Thermal solutions vendors have developed reference designs for the Pentium II Processor — Low Power. Refer to Section 7.0 for a list of vendors for each type of solution. Two types of thermal solutions are available to accommodate various system design requirements:

- Heatsink
- Fan heatsink

5.1 CompactPCI Component Height Requirements

The heatsink and fan solutions were designed to meet a single-slot or double-slot CompactPCI (CPCI) z-height constraints. Standard heatsinks or fans may be used for designs that do not need to meet the CPCI requirement. The z-height requirement for the single-slot CPCI heatsink is 13.71 mm - (2.54 mm + 0.25 mm) (PBGA height plus tolerance) - (0.25) (interface material thickness) (0.25 mm) = 10.66 mm (see Figure 2). For a double-slot heatsink solution, the maximum z-height allowed is 29.47 mm (see Figure 3).

Refer to Table 4, “Vendor List” on page 14 for information on obtaining CompactPCI Specification.

Figure 2. Single-Slot CompactPCI Z-Height Specification

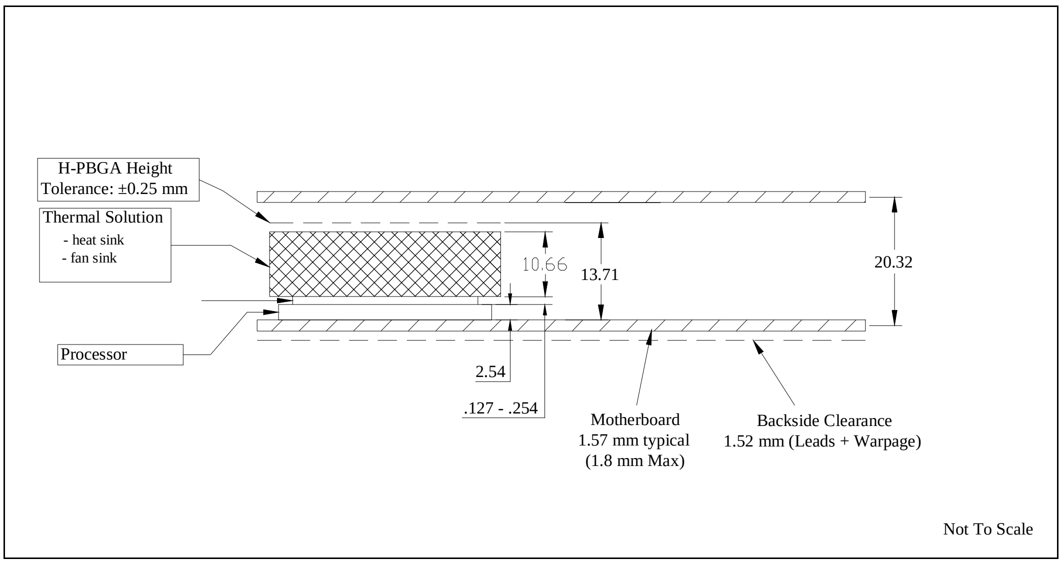
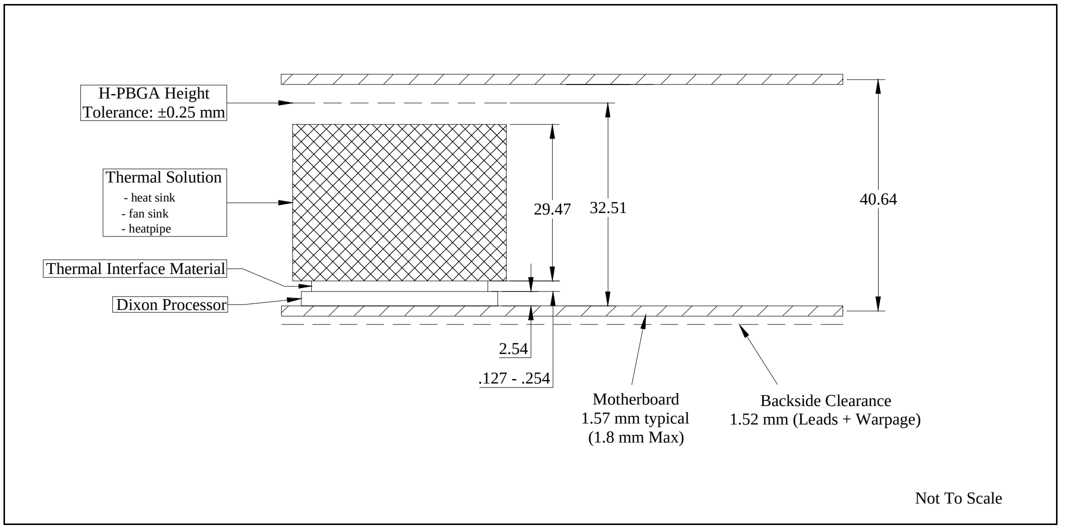


Figure 3. Double-Slot CompactPCI Z-Height Specification



5.2 Heatsink Solutions

5.2.1 Theory of Heatsink Operation

A heatsink is simply a metal surface with pins or fins rising up off the surface. Heatsinks are used to cool electronic devices by expanding the surface area of the part to which it is attached, increasing the amount of heat that can be cooled by the ambient air. A main characteristic of heatsinks is thermal resistance (θ), measured in °C/W. For example, if a component has a heatsink with a thermal resistance $\theta = 2°$ C/W, then for every watt of heat it dissipates its temperature increases by 2° C. The larger the heatsink, the more surface area it has, and the better its thermal resistance.

5.2.2 Considerations for Implementing a Heatsink Thermal Solution

The following points should be considered when evaluating heatsink thermal solutions:

- **Cost.** Heatsink solutions typically are cheaper than the fan solutions.
- **Flexibility in x, y and z dimensions.** Based on the amount of airflow available in the system, a design may require a larger heatsink to dissipate a specified amount of heat. System designers may need to be flexible in at least one or two dimensions.
- **System airflow.** It is desirable to have some system airflow to allow heat to be removed from the heatsink.

5.3 Fan Solutions

Passive-active fan heatsink solutions provide airflow and require little or no system airflow. Active fan heatsink solutions incorporate a fan that is attached to the solution. They can handle a load of up to 160 watts.

5.3.1 Theory of Fan Operation

The typical fan involves a motor and a propeller. The motor can be either an AC induction motor or a brushless DC motor. The air that a fan produces blows parallel to the fan's blade axis. These fans can be made to blow a significant amount of air, but they work against low pressure. Fans can be used alone to ventilate cool intake air through the processor, pushing warm air out. Or, they can be used in passive thermal solutions to blow hot air off of heatsinks.

5.3.2 Considerations for Implementing a Fan Thermal Solution

The following points should be considered when evaluating fan thermal solutions:

- **Performance at a moderate cost.** Fan solutions typically cost more than heatsink solutions.
- **System airflow.** When there is no system airflow, a dedicated fan attached above the component provides an excellent source of airflow, which can ensure prompt removal of heat from the heat source.
- **Flexibility in x, y or z dimensions.** The size of the required fan solution can vary according to the amount of heat that must be dissipated, the availability of system airflow, and other factors. To achieve certain thermal requirements, a system designer may need to be flexible with one or more dimensions of the design.

6.0 Related Documents

These documents are available for download from Intel's World Wide Web site at http://www.intel.com.

Table 3. Related Documents

Document	Order Number
Mobile Pentium® II Processor in BGA Package at 366 MHz, 333 MHz, 300PE MHz, and 266PE MHz datasheet	245103
AP-586 Pentium® II Processor Thermal Design Guidelines	243331
Intel Packaging Handbook	240800
Pentium® II Processor at 333 MHz, 300 MHz, 266 MHz, and 233 MHz datasheet	243335
Pentium® II Processor at 350 MHz, 400 MHz and 450MHz datasheet	243657
Pentium® II Processor Specification Update	243337

7.0 Vendor List

This vendor list is provided as a service to our customers for reference only. The inclusion of this list should not be considered a recommendation or product endorsement by Intel Corporation.

Table 4. Vendor List (Sheet 1 of 2)

Vendor	Vendor Part #
HeatSink and Fan Vendors	
SHICOH ENGINEERING CO. LTD. 3854-1 Shimotsuruma Yamato City, Kanagawa-Ken 242-001 Japan http://www.evox-rifa.com Phone: 81-462-78-3570 Fax: 81-462-78-3576	**Single Fan:** S4407D-5 (uses pins)
SUMITOMO PRECISION PRODUCTS CO. LTD. C/O Sumitronics, Inc. 2900 Patrick Henry Dr. Santa Clara, CA 95054 Phone: 408-566-8215 Fax: 408-980-1409 JAPAN: Email: heatsink@spp.co.jp Phone: 81-6-6489-5832 Fax: 81-6-6489-5879	**Corrugated (Folded Fin) Heatsink:** AXH1174-001 (uses pins)
THERMALLOY, INC. 2021 W. Valley View Lane Dallas Texas 75234-8993 Email:sales@thermalloyusa.com Outside of USA, refer to web page for contact information: http://www.thermalloy.com Phone: (972) 243-4321 Fax: (972) 241-4656	**Extruded Heatsink:** 21933 w/o thermal grease (uses pins)
PANASONIC (KME) NORTH AMERICA: **Panasonic Industrial Co.** 15075 SW Kell Parkway Suite B Beaverton, OR 97006 Email: bishmanr@panasonic.com Phone: 503-641-8743 Fax: 503-643-8933 JAPAN: **Kyushu Matsushita Electric** 2111 UEDA USA Oita, 879-04, JAPAN Email: PAN42482@pios.kme.mei.co.jp Phone: (0978) 37-1991 Fax: (0978) 37-3502 Elsewhere: Contact a local Panasonic Sales Office.	**Single Fan:** UDQFNGE01F (uses clips) UDQFNGE02F (uses pins)
Sunonwealth 135 E Live Oak Ave. #208 Arcadia, CA 91006 Email: sunon@gus.net Phone: 949-583-9802 Fax: 949-583-9785	**Single Fan:** 054006BH04 (uses pins)

Table 4. Vendor List (Sheet 2 of 2)

Vendor	Vendor Part #
AAVID (USA) One Kool Path, P.O. Box 400 Laconia, New Hampshire 03247 Web site: http://www.aavid.com Phone: (603) 528-3400 Fax: (603) 528-1478	**Extruded Heatsink:** NP970482 (uses pins) NP971803 (uses pins) NP971804 (uses pins)
Interface Material Vendors	
MicroSi (Thermal Grease) 1028 S 51st St. Phoenix, AZ 85044 Phone: 602-893-8898 Fax: 602-893-8637	
Thermagon, Inc. 3256 W. 25th St. Cleveland, OH 44109-1668 Phone: 888-246-9050 Fax: 216-741-3943	
Air Velocity Meter Supplier	
Kurz Instruments, Inc. 2411 Garden Road Monterrey, CA 93940 Phone: 800-424-7356	
Temperature Measurement Supplier	
Omega Engineering, Inc. One Omega Drive P.O. Box 4047 Stamford, CT 06906 Phone: 1-800-622-2378	
CompactPCI Specification	
Order from: Rogers Communication 301 Edgewater Place, Suite 220 Wakefield, MA 01880 Phone: 617-224-1100 Fax: 617-224-1239	